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ADVANCED TRAINING SYSTEMS

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I. INTRODUCTION

A. General Introduction

Training is a major endeavor in all modern societies: new personnel must be trained to perform the task(s) which they were hired to perform, continuing personnel must be trained to upgrade or update their ability to perform assigned tasks, and continuing personnel must be trained to tackle new tasks. Common methods include training manuals, formal classes, procedural computer programs, simulations, and on-the-job training. The latter method is particularly effective in complex tasks where a great deal of independence is granted to the task performer. Of course, this training method is also the most expensive and may be impractical when there are many trainees and few experienced personnel to conduct on-the-job training.

NASA's training approach has focussed primarily on on-the-job training in a simulation environment for both crew and ground-based personnel. This process worked relatively well for both the Apollo and Space Shuttle programs. Space Station Freedom and other long range space exploration programs coupled with limited resources dictate that NASA explore new approaches to training for the 1990's and beyond.

This report describes specific autonomous training systems based on artificial intelligence technology for use by NASA astronauts, flight controllers, and ground-based support personnel that demonstrate an alternative to current training systems. In addition to these specific systems, the evolution of a general architecture for autonomous intelligent training systems that integrates many of the features of "traditional" training programs with artificial intelligence techniques is presented. These Intelligent Computer-Aided Training (ICAT) systems would provide, for the trainee, much of the same experience that could be gained from the best on-the-job training. By integrating domain expertise with a knowledge of appropriate training methods, an ICAT session should duplicate, as closely as possible, the trainee undergoing on-the-job training in the task environment, benefiting from the full attention of a task expert who is also an expert trainer. Thus, the philosophy of the ICAT system is to emulate

the behavior of an experienced individual devoting his full time and attention to the training of a novice--proposing challenging training scenarios, monitoring and evaluating the actions of the trainee, providing meaningful comments in response to trainee errors, responding to trainee requests for information, giving hints (if appropriate), and remembering the strengths and weaknesses displayed by the trainee so that appropriate future exercises can be designed.

B. BACKGROUND

Since the 1970's a number of academic and industrial researchers have explored the application of artificial intelligence concepts to the task of teaching a variety of subjects [Sleeman and Brown, 1982; Yazdani, 1986; Wenger, 1987] (e.g., computer programming in Lisp [Anderson, 1985; Anderson, Boyle and Reiser, 1985] and Pascal [Johnson and Soloway, 1985], economics [Shute and Bonar, 1986], geography [Carbonell, 1970], and geometry [Anderson, Boyle and Yost, 1985]). The earliest published reports which suggested the applications of artificial intelligence concepts to teaching tasks appeared in the early 1970's [Carbonell, 1970; Hartley and Sleeman, 1973]. Hartley and Sleeman [Hartley and Sleeman, 1973] actually proposed an architecture for an intelligent tutoring system. However, it is interesting to note that, in the sixteen years which have passed since the appearance of the Hartley and Sleeman proposal, no agreement has been reached among researchers on a general architecture for intelligent tutoring systems [Yazdani, 1986].

Along with the extensive work on intelligent tutoring systems for academic settings has come the development of systems directed at training. Among these are Recovery Boiler Tutor [Woolf, Blegen, Jansen, and Verloop, 1986], SOPHIE [Brown, Burton and de Kleer, 1982], and STEAMER [Hollan, Hutchins and Weitzman, 1984]. These differ from the tutoring systems mentioned above in providing a simulation model with which the student or trainee interacts. Although these intelligent training systems each use the interactive simulation approach, they each have very different internal architectures. Further, there appears to be no agreement, at present, on a general architecture for such simulation training systems. The work reported here builds on these previous efforts and our own work [Loftin, Wang, Baffes and Rua, 1987; Loftin, Wang, Baffes, and Hua, 1988; Loftin, Wang, Baffes, and Hua, 1989a and b] to develop specific intelligent training systems as well as a general approach to the design of intelligent training systems which will permit the production of such systems for a variety of tasks and task environments with significantly less effort that is now required to "craft" such a system for each application.

C. TRAINING VERSUS TUTORING

The ICAT systems and architecture described here have been developed with a clear understanding that training is not the same

as teaching or tutoring [Harmon, 1987]. An industrial or governmental training environment differs in many ways from an academic teaching environment. These differences are important in the design of an architecture for an intelligent training system:

- Assigned tasks are often mission-critical, placing the responsibility for lives and property in the hands of those who have been trained.
- Personnel may already have significant academic and practical experience to bring to bear on their assigned task.
- Trainees make use of a wide variety of training techniques, ranging from the study of comprehensive training manuals to simulations to actual on-the-job training under the supervision of more experienced personnel.
- Many of the tasks offer considerable freedom in the exact manner in which they may be accomplished.

Those undergoing training for complex tasks are usually well aware of the importance of their job and the probable consequences of failure. While students are often motivated by the fear of receiving a low grade, trainees know that human lives and/or expensive equipment may depend on their skill in performing assigned tasks. This means that trainees may be highly motivated, but it also imposes on the trainer the responsibility for the accuracy of the training content (i.e., verification of the domain expertise encoded in the system) and the ability of the trainer to correctly evaluate trainee actions. The ICAT approach is intended, not to impart basic knowledge, but to aid the trainee in developing skills for which he already has the basic or "theoretical" knowledge. In short, this training system architecture is designed to help a trainee put into practice that which he already intellectually understands. The system must take into account the type of training that both precedes and follows, building on the knowledge gained from training manuals and rule books while preparing the trainee for and complementing the on-the-job training which may follow. Perhaps most critical of all, trainees must be allowed to carry out an assigned task by any valid means. Such flexibility is essential so that trainees are able to retain, and even hone, an independence of thought and develop confidence in their ability to respond to problems, even problems which they have never encountered and which their trainers never anticipated.

IV. APPLICATIONS

The ICAT architecture was originally applied to a training system for NASA flight controllers learning to deploy satellites from the Space Shuttle. The same architecture has been used in the construction of ICAT systems for training astronauts for SpaceLab missions and engineers who test the Space Shuttle main

propulsion system. Although these tasks are quite different and are performed in very dissimilar environments, the same system architecture has proven to be adaptable to each. Below is a brief summary of the specific systems that have been built or are currently under development:

A. PD/ICAT: [Payload-assist module Deploys/ICAT System]

A comprehensive intelligent computer-aided training system for use by Flight Dynamics Officers in learning to deploy PAM (Payload-Assist Module) satellites from the Space Shuttle. PD/ICAT contains four expert systems that cooperate via a blackboard architecture.

B. VVL/ICAT: [Vacuum Vent Line/ICAT System]

A PC-based intelligent computer-aided training system for use by mission and payload specialists in learning to perform fault detection, isolation, and reconfiguration on the Spacelab VVL system. VVL/ICAT consists of an integrated expert system and graphical user interface.

C. MPP/ICAT: [Main Propulsion Pneumatics/ICAT System]

A comprehensive intelligent computer-aided training system for use by test engineers at NASA/Kennedy Space Center in learning to perform testing of the Space Shuttle Main Propulsion Pneumatics system. MPP/ICAT is currently under development and makes use of the same architecture as PD/ICAT.

D. IPS/ICAT: [Instrument Pointing System/ICAT System]

A comprehensive intelligent computer-aided training system for use by payload and mission specialists at NASA/Johnson Space Center and Marshall Space Flight Center in learning to utilize the IPS on Spacelab missions. IPS/ICAT is currently under development and makes use of the same architecture as PD/ICAT.

III. A GENERAL ARCHITECTURE FOR INTELLIGENT TRAINING SYSTEMS

The projects described in the previous section have served as vehicles to aid in the design and refinement of an architecture for intelligent training systems that has significant domain-independent elements and is generally applicable to training in procedural tasks common to the NASA environment. The ICAT system architecture is modular and consists of five basic components:

- A user interface that permits the trainee to access the same information available to him in the the task environment and serves as a means for the trainee to take actions and communicate with the intelligent training system.

- A domain expert which can carry out the task using the same information that is available to the trainee and which also contains a list of "mal-rules" (explicitly identified errors that novice trainees commonly make).
- A training session manager which examines the actions taken by the domain expert (of both correct and incorrect actions in a particular context) and by the trainee and takes appropriate action(s). [Loftin, Baffes and Wang, 1988]
- A trainee model which contains a history of the individual trainee's interactions with the system together with summary evaluative data.
- A training scenario generator that designs increasingly-complex training exercises based on the knowledge of the domain expert, the current skill level contained in the trainee's model, and any weaknesses or deficiencies that the trainee has exhibited in previous interactions. [Loftin, Wang, and Baffes, 1988; Loftin, Wang, and Baffes, 1989]

Figure 1 contains a schematic diagram of the ICAT system. Note that provision is made for the user to interact with the system in two distinct ways and that a supervisor may also query the system for evaluative data on each trainee. The blackboard serves as a common repository of facts for all five system components. With the exception of the trainee model, each component makes assertions to the blackboard, and the expert system components look to the blackboard for facts against which their rules pattern match. A comprehensive effort has been made to clearly segregate domain-dependent from domain-independent components.

IV. SYSTEM INTEGRATION

The ICAT architecture described above was originally implemented in a Symbolics 3600 Lisp environment using Inference Corporation's ART for the rule-based components. The architecture is currently available for unix workstations. The user interface is implemented in X-Windows, the rule-based components in CLIPS [CLIPS is the acronym for a NASA-developed expert system shell written in C], and supporting code in C.

V. TRAINING PERFORMANCE

The original system developed with this architecture (PD/ICAT) has been used by both expert and novice flight controllers at NASA/Johnson Space Center. An extensive investigation of the performance of novices using the system has been conducted. Figure 2 shows two measures of performance: (1) the time required to perform the nominal task as a function of the number of training experiences and (2) the number of errors made during the performance of the nominal task as a function of the number of training experiences. It is interesting to note that,

although the novices used in this investigation had very different levels of prior experience related to the task, all novices rapidly approached the same level of proficiency.

VI. CONCLUSIONS

A general architecture for ICAT systems has been developed and applied to the construction of three ICAT systems for very different tasks. Use by novices of an ICAT application built upon this architecture has shown impressive trainee performance improvements. With further refinement and extension, this architecture promises to provide a common foundation upon which to build intelligent training systems for many tasks of interest to the government, military, and industry. The availability of a robust architecture that contains many domain-independent components serves to greatly reduce the time and cost of developing new ICAT applications.

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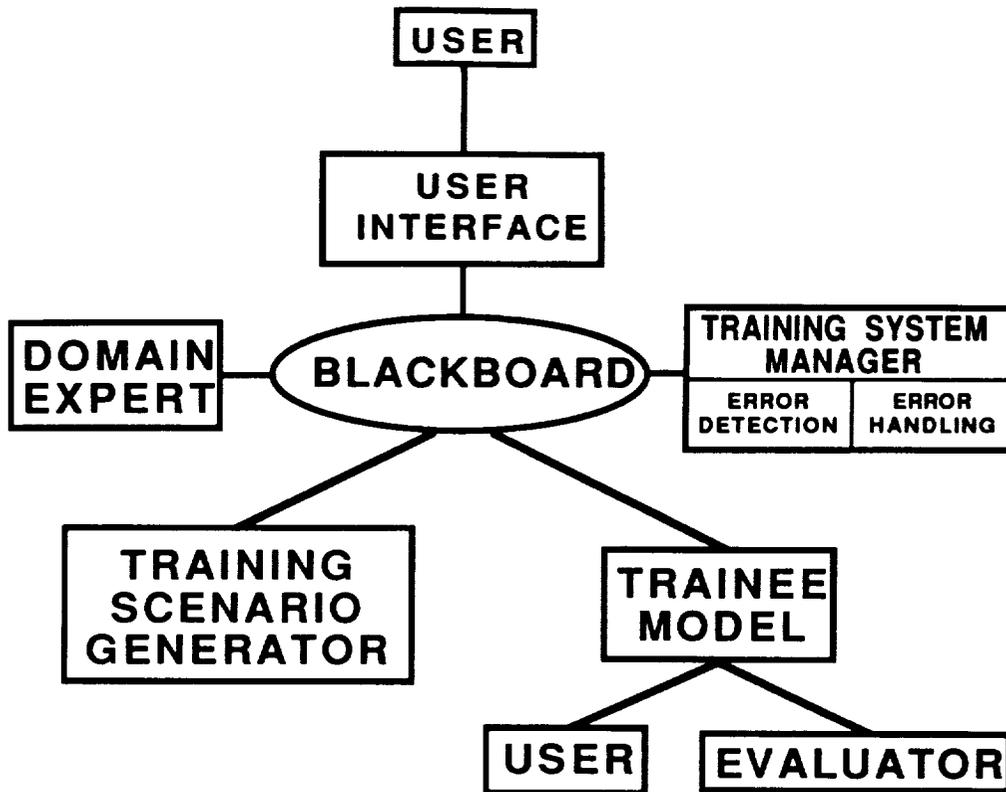


Figure 1. A Schematic Diagram of the General Architecture

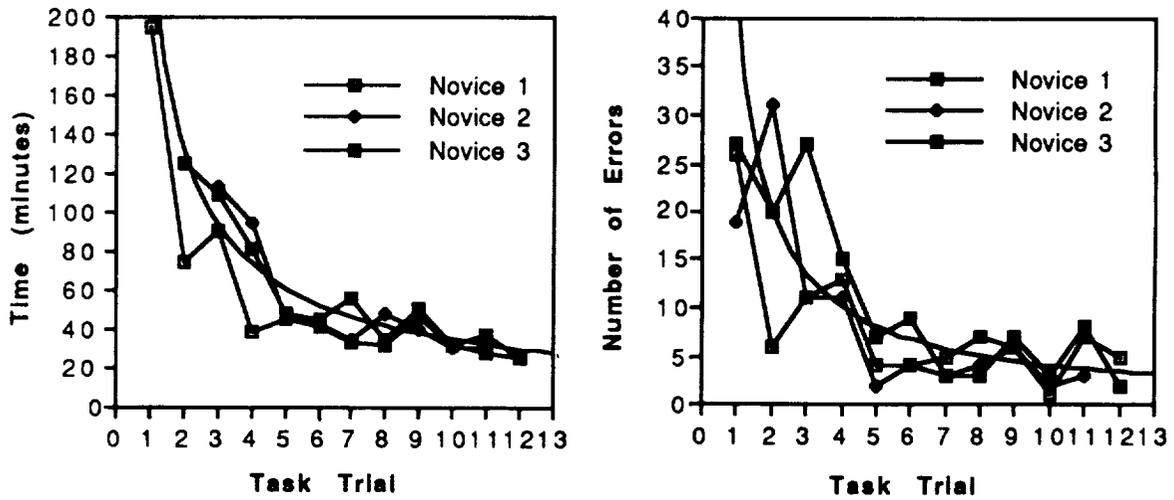


Figure 2. Performance of Novices Using the PD/ICAT System